REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 11/15/1997	3. REPORT TYPE AND DATES COVERED Final Progress Report

4. TITLE AND SUBTITLE
Ultra-Wideband Electromagnetics

5. FUNDING NUMBERS
DAAG04-93-2-0010

6. AUTHOR(S)
Lawrence Carin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Duke University
Department of Electrical and Computer Engineering
Durham, NC 27708-0291

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 32449.8-EL-ISP

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release: distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Electromagnetic models have been developed for foliage-penetrating radar and have been transitioned to the Army Research Laboratory (Adelphi, MD) for target classification algorithms.

14. SUBJECT TERMS
radar, foliage penetration

15. NUMBER OF PAGES
3

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION ON THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500 **Standard Form 298**
(Rev.2-89)

MASTER COPY: PLEASE KEEP THIS "MEMORANDUM OF TRANSMITTAL" BLANK FOR REPRODUCTION PURPOSES. WHEN REPORTS ARE GENERATED UNDER THE ARO SPONSORSHIP, FORWARD A COMPLETED COPY OF THIS FORM WITH EACH REPORT SHIPMENT TO THE ARO. THIS WILL ASSURE PROPER IDENTIFICATION. <u>NOT TO BE USED FOR INTERIM PROGRESS REPORTS</u>; SEE PAGE 2 FOR INTERIM PROGRESS REPORT INSTRUCTIONS.

MEMORANDUM OF TRANSMITTAL

U.S. Army Research Office
ATTN: AMSRL-RO-RI (Hall)
P.O. Box 12211
Research Triangle Park, NC 27709-2211

- ☐ Reprint (Orig + 2 copies)
- ☐ Technical Report (Orig + 2 copies)
- ☐ Manuscript (1 copy)
- ☒ Final Progress Report (Orig + 2 copies)
- ☐ Related Materials, Abstracts, Theses (1 copy)

CONTRACT/GRANT NUMBER: DAAH-04-93-2-0010

REPORT TITLE: Ultra-Wideband Electromagnetics

is forwarded for your information.

SUBMITTED FOR PUBLICATION TO (applicable only if report is manuscript):

Sincerely,
Lawrence Carin, PI

I. List of Manuscripts Submitted/Published under ARO Support

Vitebskiy, S.; Sturgess, K.; Carin, L., "Short-pulse plane-wave scattering from buried perfectly conducting bodies of revolution," IEEE Transactions on Antennas and Propagation, Volume: 44, pp. 143 –151, Feb. 1996

Vitebskiy, S.; Carin, L., "Moment-Method Modeling of Short-Pulse Scattering from and the Resonances of a Wire Buried Inside a Lossy half space," IEEE Transactions on Antennas and Propagation , Volume: 43, pp. 1303-1312, Nov. 1995.

Kralj, D.; Carin, L., "Wideband dispersion measurements of water in reflection and transmission," IEEE Transactions on Microwave Theory and Techniques, Volume: 42, pp. 553 –557, April 1994

II. Scientific Personnel

Faculty: Lawrence Carin (PI)
Graduate students: David Kralj (PhD 1995) and Stanislav Vitebskiy (PhD 1996)

III. Invention Reports

None

IV. Scientific Progress and Accomplishments

Ground penetrating radar (GPR) has been a topic of intense research for several decades. As part of these studies, significant attention has been directed toward understanding electromagnetic propagation in the earth, as well as on the study of scattering from buried targets. The insight gained from such phenomenological studies can be applied to the development of new signal processing and imaging schemes, as well as to the design of new GPR systems.

Most previous investigations of GPR phenomenology have examined narrowband operating conditions. Recently, however, there has been an interest in ultra-wideband short-pulse radar for ground penetrating applications. Such systems generate short pulse waveforms with large instantaneous bandwidth, giving rise to time-domain phenomenology which is fundamentally different than that of narrowband systems. As a first step toward understanding the wave physics associated with short-pulse scattering from buried targets, we consider in this project short-pulse plane-wave scattering from buried perfectly conducting bodies of revolution (BOR). To make such a study tractable, the soil is modeled as a lossy, dispersive halfspace, and the axis of revolution of the buried target is assumed normal to the air-ground interface; this assumption restricts the target orientation but allows one to view the target-halfspace composite as a single BOR. We solve the scattering problem in the frequency domain via the Method of Moments (MoM), using an algorithm analogous to those developed previously for scattering from

BORs in free space. After performing the MoM analysis over the bandwidth of the incident pulse, the time-domain scattered fields are synthesized via Fourier transform.

Several authors have investigated the MoM analysis of plane-wave scattering from conducting, dielectric, and hybrid BORs in free space. These algorithms take advantage of the azimuthal periodicity inherent in the incident fields, induced currents, and the free-space Green's function. The case of scattering from a buried BOR is complicated significantly by the fact that the half-space Green's function is a dyadic, each term of which is expressed in terms of highly oscillatory Sommerfeld integrals and their spatial derivatives. Thus, to make the MoM analysis of a buried BOR tractable, highly efficient techniques are required for the computation of the dyadic half-space Green's function; this is especially true for the wideband applications of interest here.

To compute the components of the half-space Green's function efficiently over wide bandwidths, we employ the method of complex images. In this technique, the spectral Green's function inside the Sommerfeld integral is fit via Prony's method (or any other parametric algorithm, such as the matrix-pencil method to a finite sum of complex exponentials, the integrals of which can be expressed in closed form via Sommerfeld's identity. This formulation is highly efficient because the numerical burden is shifted from laboriously computing the Sommerfeld integrals via brute-force numerical integration to the relatively efficient task of performing a parametric fit to the spectral Green's function. Of importance for the BOR problem, after applying the method of complex images, each component of the dyadic Green's function is written as a sum of free-space Green's function (or its spatial derivatives) with complex source points. Thus, after applying the method of complex images, the techniques used for the MoM analysis of scattering from BORs situated in freespace – which take advantage of properties of the freespace Green's function – can be transferred directly to the problem of scattering from buried BORs.

The development of the method of complex images represents a seminal advance in that it now makes possible the efficient analysis of wideband scattering from complex buried structures. Algorithms which have been developed previously for buried-target scattering – which were restricted to narrowband applications due to the inherent difficulty in efficiently computing Sommerfeld integrals – can now be updated for wideband operation. This project demonstrates how this can be achieved through consideration of short-pulse scattering from buried perfectly conducting BORs. Although short-pulse scattering has been considered previously for buried conducting wires, to the best knowledge of the authors, this paper represents the first rigorous analysis of short-pulse scattering from complex buried targets (there are examples, however, in which transient scattering has been considered for specialized antenna and buried-target geometries).

V. Technology Transfer

The computer models developed under this program have been delivered to the Army Research Laboratory (Adelphi, MD)